The Effects of Weak Gravitational Lensing on Determinations of the Cosmology from Type Ia Supernovæ

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Abstract.

Underlying cosmologies with deceleration parameter, $q_0 = -0.51^{+0.03}_{-0.24}$, may be interpreted as having $q_0 = -0.55$, on the basis of weak gravitational lensing effects.

1. Computing the Three-Dimensional Shear

The algorithm used for determining the three-dimensional shear has been described fully by Couchman, Barber & Thomas (1998). Of particular interest is the variable softening feature in the algorithm, designed to distribute the mass of each particle within a radial profile, which depends on its specific environment.

The algorithm has been applied to a number of different cosmological N-body simulations available from the Hydra consortium[1]; see, for example, Barber, Thomas & Couchman (1999).

2. The Effects of Weak Lensing on Determinations of the Deceleration Parameter

Both Riess et al. (1998) and Perlmutter et al. (1999), point to cosmologies which are close to the $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$ cosmological simulation (designated LCDM) I have analyzed in terms of weak lensing. I shall therefore discuss the dispersions in magnification and the impact on determinations of the deceleration parameter, q_0, with regard to this assumed underlying cosmology.

By considering Type Ia supernovæ sources at ten evenly spaced redshifts, z, between $z = 0$ and $z = 1$, the resulting distributions of the magnifications show the expected increasing dispersions with z, which could be interpreted as observational dispersions in the peak magnitudes. They are equivalent to differences in distance modulus, m, and these differences have been evaluated to correspond to the 2σ range in the magnification distribution, denoted by μ_{low} and μ_{high}.

Riess et al. (1998) have recognized that weak lensing of high-redshift Type Ia supernovæ can alter the observed magnitudes and quote the findings of Wambsganss et al. (1997),

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[1] http://coho.astro.uwo.ca/pub/data.html

i.e., that the light will be on average demagnified by 1% at $z = 1$ in a universe with a non-negligible cosmological constant. They state that the size of this effect is negligible. Perlmutter et al. (1999) assume that the effects of magnification or demagnification will average out, and that the most over-dense lines of sight should be rare for their set of 42 high-redshift Type Ia supernovæ. However, they note that the average (de)amplification bias from integration of the probability distributions is less than 1% for redshifts of $z \leq 1$. My work has shown that, in the LCDM cosmology, a source at $z = 1$ will have on average (de)amplification bias of 3.4% ($\mu_{\mathrm{peak}} = 0.966$), and 1.3% at $z = 0.5$. Whilst these effects are still rather small, there is a significant probability of observing highly magnified Type Ia supernovæ; $97\frac{1}{2}$% of all lines of sight display a range of magnifications up to 1.191 at $z = 1$, and this range introduces an approximate 2σ (skewed) dispersion of 0.252 magnitudes.

On the evidence of the data, an underlying cosmology with $q_0 = -0.51^{=0.03}_{-0.24}$ may be interpreted as having $q_0 = -0.55$, from the use of perfect standard candles (without intrinsic dispersion), arising purely from the effects of weak lensing. This dispersion in q_0 is somewhat larger than that found by Wambsganss et al. (1997) based on a cosmology with $\Omega_m = 0.4$, $\Omega_\Lambda = 0.6$, because of the broader magnification distribution at $z = 1$. Fluke (1999) has analyzed his data differently to obtain dispersions in q_0. His much larger dispersions compared with mine, come primarily from the much higher values of μ_{high} in his results.

Acknowledgments

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